Journal of Terrestrial Observation

Volume 2, Issue 2	*Spring 2010*	*Article 5*

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 ISSN 1946-1143.

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ABSTRACT

Numerous scientific research and engineering programs are being carried out globally in an effort to monitor environmental degradation, natural and anthropogenic disasters. These are part of a process to predict possible catastrophic events and help minimize their devastating impact on the environment and human life. Many of these programs, sometimes referred to as Early Warning Systems (EWSs), have been documented with detailed information on approach and technology utilization in the areas of sensor design for real-time multiple-source data collection, data transmission, evaluation and analysis, timely dissemination of early warning information and efficient response to such information. While some EWSs are indispensable in our efforts for environmental sustainability, others have not performed as expected or designed. This paper examines the literature on EWSs, the level of utilization of remote sensing technology and the potential trends for future systems. An evaluation of the strengths and weaknesses of the different systems was performed. Status and processes were reviewed for early warning systems, as related to land degradation, biodiversity, atmospheric and air quality, aquatic environments and freshwater quality assessment. The review indicated not all monitoring systems constituted fully integrated EWSs, and not all natural or anthropogenic pollution categories and consequent disasters have working EWSs. Remote sensing and related technologies have been successfully used to analyze and predict adverse impacts related to land degradation and certain physical and biological pollution variables related to water quality. Advances in sensor technologies have also resulted in more reliable, high frequency and automated samplers for data collection in water quality studies. Europe and North America have some of the most advanced EWSs, while EWS applications in Africa and Asia have improved considerably in recent years. EWSs have generally been reliable in helping reduce some of the negative impacts of environmental degradation, pollution and disasters.

Acronyms and abbreviations are listed beginning on page 40 for readers not familiar with some of the many acronyms/abbreviations used in this paper.

INTRODUCTION

For centuries, humans together with other organisms have experienced major impacts from environmental degradation and destruction of natural resources. Some of these incidences have been caused by natural climatic and geologic processes and others by anthropogenic activities resulting in point and nonpoint source pollution of water and other natural resources. In recent years, concerns have increased regarding possible acts of terrorism through the use of bioweapons on surface water resources. Deadly pathogens (e.g., anthrax and Cryptosporidiosis) and biotoxins (e.g., ricin and saxitoxin) are potentially resistant to chlorine disinfection, and their delivery through public water sources to the public could be catastrophic (Salem, 2003).

Advances in technology have now made it possible to monitor most pollutants and environmental degradation phenomena on a real-time basis to detect adverse trends and make reliable predictions of possible impacts in the form of early warning systems (EWSs). An EWS is an integrated system for monitoring, collecting data, analyzing, interpreting, and communicating monitored data, which can then be used to make decisions early enough to protect public health and the environment and to minimize unnecessary concern and inconvenience to the public (USEPA, 2005a). While many programs are involved in environmental monitoring activities, very few are fully integrated EWSs that detect contamination and degradation events early enough in time to allow for an effective response capable of alleviating the impact of a potentially disastrous environmental phenomenon. This study examines EWSs for environmental monitoring and evaluates the systems that have best served to protect the environment and human life.

Biogenic- and anthropogenic-related environmental and natural resources degradation has direct economic and health impacts on affected regions. Land and water degradation as well as natural disasters such as floods and droughts have led to famine, hunger, disease, and death for millions of people. Globally, as of 2009, FAO estimates that 1.02 billion people are hungry and undernourished (FAO, 2009). IPCC (IPCC, 2007) estimates that by 2100, regions of arid and semi-arid land in Africa are expected to expand by 5 to 8 percent, or 60 to 90 million hectares, resulting in agricultural losses of between 0.4 and 7 percent of GDP in northern, western-central, and southern Africa. Loss in biodiversity from environmental degradation and fragmentation of habitats has resulted in the extinction or endangerment of numerous plant and animal species. In India, more than U.S.$10 billion is lost annually from human-induced land degradation alone, causing productivity losses of around U.S.$2.4 billion (UNEP, 2002). Financial losses in the United States from poor water quality (WQ) due to uncontrolled soil erosion total more than $4 billion per year (Hrubovcak et al., 1995).

The precarious state of the global environment has resulted in numerous efforts by the UN, governments, NGOs, and academia to fund research and implement policies and projects designed to monitor and help curb the trend toward further environmental degradation. To achieve this goal, EWSs have been set up to monitor the environment and predict potential adverse effects within a reasonable time to allow for measures to be taken to reduce the otherwise harsh impacts. Since environmental degradation, pollution, and natural disasters are global problems, it is important to know how certain EWSs have been successful, so as to encourage the replication of such systems in similar hot spots (Quansah, 2007).

OBJECTIVES

The primary objective of this paper is to assess existing monitoring and early warning systems described in the literature and to evaluate their successes in minimizing pollution, environmental degradation, and the impacts of natural disasters. Of special interest are EWSs used in water quality protection, information gathering, interpretation, communication, and utilization of derived information in efficient response implementation. This study examines the extent to which modern technologies such as remote sensing are being utilized in EWSs, as well as the strengths and weaknesses of existing EWSs.

REVIEW OF EARLY WARNING SYSTEMS

The method used in reviewing the different environmental degradation EWSs was by grouping them into different monitoring categories as related to land and water degradation and associated impacts. The general approach in data collection, analysis, information communication, and response implementation for different EWSs was then reviewed. Accompanying illustrations and other documents come from the peer-reviewed literature and EWS programs described in conference papers and reports.

The essential structure of any EWS depends on the objectives of the system to provide important, timely information on specific phenomena to end-users and decision-makers, thereby enabling effective response. These objectives determine the processes utilized in activities related to data collection, processing, interpretation, dissemination of information, and subsequent response. The types of data utilized in EWSs are typically environmental data and related socio-economic data. The nature of these data, method of collection, and the technologies used are directly related to the type of environmental issue under study and the final EWS to be created.

Depending on factors like the spatial and temporal scale of a specific environmental degradation, the geographic area, size of the phenomenon, and the objectives of the particular monitoring program, some systems may not be considered as fully integrated EWS. Accordingly, different environmental degradation awareness programs are classified as EWSs, information dissemination systems (IDSs), or data dissemination systems (DDSs), depending on an organization's objectives and activities in these areas (UNCCD and Italian Cooperation, 1999). While these different systems might be operating independently, they sometimes collaborate in data and information exchange during the establishment of some EWSs, especially in situations of globally perceived risk from environmental degradation or public health exigencies. Examples of fully integrated EWSs include:

1. US Agency for International Development's (USAID) Famine Early Warning System (FEWS) (USGS-EROS, 2010. Retrieved from http://earlywarning.usgs.gov), established in the late 1980s utilizing satellite data from NASA and NOAA
2. South African Development Cooperation's (SADC) Food Security Programme (UNCCD and Italian Cooperation, 1999)
3. Food and Agricultural Organization's (FAO) Global Information & Early Warning System (GIEWS) on Food and Agriculture (ISDR, 2009)
4. United Nation Environmental Programme's (UNEP) Division of Early Warning and Assessment (DEWA) (ISDR, 2010)
5. World Food Programme's (WFP) Vulnerability Analysis and Mapping (VAM) (UNCCD and Italian Cooperation, 1999)

All well integrated EWSs tend to contain four major components:

- Information and multidisciplinary data collection on the phenomenon
- Evaluation, processing, and analysis of collected data
- Dissemination of warning information to policy-makers and end-users
- Implementation of an effective and timely response to the early warnings issued

While advanced technologies, such as remote sensing and contaminant samplers, have been utilized in data collection in most environmental monitoring systems, it is important to state that integrated EWSs incorporate multidisciplinary data as well. Socio-economic indicators such as population growth, market trends, food availability and prices, health status, prevalence of malnutrition, and the sustainability of both agriculture and industry serve as important components of multidisciplinary data for EWSs. High-tech data collection procedures and both statistical and integral analyses are involved in providing regular applications in EWSs.

Setting up EWSs could be very expensive and labor intensive and requires collaborative efforts in human, financial, and institutional resources. Systems that are versatile in detecting multiple contaminants and degradation are more expensive to set up and maintain. EWSs are also expected to be standardized and reliable with continuous monitoring and variable sampling frequencies with minimal false negative and false positive results to enhance reliable contamination detection and source identification (USEPA, 2005a).

EWSs FOR LAND DEGRADATION MONITORING AND ASSESSMENT

Land degradation continues to be the major contributing factor for some of the world's most devastating disasters, especially related to drought and famine. There is, therefore, the need to monitor and predict such trends to help reduce associated impacts. Most land degradation EWSs are focused on producing risk/vulnerability maps and early warnings on potential trends in poor agricultural productivity, desertification, drought, deforestation, soil erosion, and bushfires in the various sub-regions of the world.

Due to the spatial (local, regional, and global) and temporal characteristics of all land degradation processes, it is important that spatial and non-spatial information on all affected areas is captured at the same specific time in a very systematic and reliable way. The common trend for data collection and monitoring is by use of earth observation (EO) technologies. Such EO data are then integrated with socio-economic data and other multidisciplinary components of EWSs. Other technologies like global positioning systems (GPS) are commonly used for monitoring deformation and geologic activities such as landslides, wild fires, and volcanic activities.

Role of Earth Observation (EO) in Land Degradation EWSs

The availability of hundreds of satellite sensors (optical and microwave), with varied spatial, temporal, spectral, and radiometric resolutions, has made EO applications in EWSs more of an issue of ability to pay for products than of technological choice. While some EWSs have utilized expensive data with fairly high spatial resolution, most organizations have made good use of less expensive, coarse data with higher temporal resolution. However, there is an application synergy between low and high spatial resolution EO data, as well as between polarimetric synthetic aperture radar (SAR) and hyper-spectral systems (Holecz et al., 2003). The use of multiple sensors with varied resolutions allows for the combination of different spatial, temporal, spectral, and radiometric resolutions to (i) identify trends and locate vulnerable areas (small-scale monitoring), and (ii) assess vulnerability and predict possible scenarios (large-scale mapping) (Holecz et al., 2003).

Most commonly used coarse resolution satellite systems for regional/global land degradation related environmental monitoring include NOAA's AVHRR, GOES, and MODIS (Aqua/Terra) sensors as well as ESA's ENVISAT and METEOSAT systems. In some well-funded EWSs, moderate- to high-resolution optical data are used to map land resources and environmental changes. Examples of such satellite sensors include NASA's and EROS's Landsat series (MSS, TM, and ETM+), CNES's SPOT series (SPOT-4 and -5), and IRS's P4&1C satellite series (IRS-WiFS and IRS-LISS) (Lantieri, 2003).

During periods of land degradation and associated conditions such as desertification and drought, physiognomic changes and differences within vegetation can be measured by the manipulation of satellite spectral radiance into useful products and index maps (Ray, 2001). Commonly derived indices and products from EO for land degradation related EWSs include Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI), Soil Adjusted Vegetation Index (SAVI), Moisture Stress Index (MSI), Leaf Area Index (LAI), and Leaf Water Content (LWC). Other EO products include vegetation types, land cover maps, digital elevation models, crop types, and biomass indices such as Net Primary Production (NPP), Rain Use Efficiency (RUE), Local NPP Scaling (LNS), Photosynthetically Active Radiation (PAR), Gross Primary Production (GPP), and Fraction of PAR (fPAR) (Lantieri, 2003). The derived indices serve as a measure of plant growth processes such as the growth rate, chlorophyll content, soil water content, and stress.

Depending on the intended objective of EWSs, EO products are used as input layers (Holecz et al., 2003) in integration with socio-economic data during environmental modeling, Geographic Information System (GIS), and statistical analysis to predict the trend and seriousness of an ongoing land degradation trend. Through this process, vulnerability maps are produced, from which predictive information is derived and early warnings issued. A typical integration of EO data and other socio-economic data for EWS analysis is USAID's FEWS. Starting from both remote sensing and agrometeorological data, FEWS establishes the basis for identifying areas potentially susceptible to famine. At the same time, by exploiting the data concerning food availability and accessibility, FEWS can facilitate assessment of the vulnerability of both geographic areas and human populations. Household food insecurity is evaluated at the lowest possible level of disaggregation, incorporating information on the different socio-economic groups within each sub-region (UNCCD and Italian Cooperation, 1999).

Risk assessment and vulnerability analysis are then conducted to produce final products, pinpointing potential land degradation trends and associated risk and impact. Some of the EWS products from these processes include vulnerability and risk index impact maps, food and water insecurity assessment maps and bulletins, crop situation reports, food supply/demand situation bulletin, crop risk index current and baseline, and predictable potential catastrophic events (UNCCD and Italian Cooperation, 1999). Wessels et al. (2003) used NPP, RUE, and LNS indices from remote sensing analysis to successfully map degradation trends in the Northern Province of South Africa.

Similarly, the Regional Centre for Mapping of Resources for Development (RCMRD) in Kenya uses crop yield forecast image products from satellite data analysis as input for food security EWS. RCMRD relates evapotranspiration data to crop growth, using the crop growth model EARS-EL, to estimate relative biomass, which serves as a predictor of the relative crop yield halfway through the growing season (Oroda, 2001).

Warning information from such drought and famine EWSs has been pivotal for international and regional organizations, as well as for aid agencies. Such information helps provide good estimates of crop yields, critically important for planning, seeking funds, and budgeting to provide food supplements and other essential needs to affected regions in Africa, Asia, and South and Central America, where drought has resulted in poor harvest, hunger, and suffering. USAID, EU, AU, WMO, UNEP, FAO, WHO, and OCHA regularly use EWSs as a guide in their strategic planning and operations. FAO uses famine and drought EWSs to estimate food and budgets needed to help drought- and famine-impacted regions of the world.

Warning Information Dissemination and Response

Once an interpretation has been completed, based on a previously established baseline of degradation severity, a prediction of the impacts and implications is made to a level of certainty dependent on the EWSs. Derived warning information is then delivered to policy-makers at local and national levels directly or through the information and data dissemination components of multilateral organizations, especially in cases of global EWSs.

The global scale of most land-related environmental degradation has resulted in the engagement of the UN and its affiliate organizations, regional leaders, and governments in collective collaborations targeted at reducing the impact of environmental degradation and pollution. It is therefore of priority and importance to UN-affiliated organizations and regional multilateral agencies to ensure that relevant early warning information reaches decision- and policy-makers. Organizations like Environment Information Systems–Africa (EIS-Africa), Society of International Development (SID), Environmental Information Systems for Sustainable Development in Africa (SISEI), Desertification Data and Information System (D-DIS), Centre for Earth Observation (CEO), Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), Global Environmental Monitoring System (GEMS), Center for Environment and Development for Arab Region and Europe (CEDARE), and United Nations Convection to Combat Desertification (UNCCD) are consistently disseminating data and informing governments and NGOs of threatening environmental degradation issues and associated impacts such as drought, famine, disease, and water scarcity. Depending on the nature of the warning information received and the anticipated impacts, most governments work proactively with regional and local leaders responsible for emergency response programs, so as to help protect their people, mitigate the environmental impact, and reduce the hardships from an inevitable adverse event.

EWSs FOR WATER QUALITY MONITORING AND ASSESSMENT

The status of water quality (WQ) and availability is often affected by adverse processes such as land degradation, climatic change, direct or indirect anthropogenic activities, and, in extreme and rare situations, the use of bioweapons in acts of terrorism. Whatever the source of water impairment, it is evidently necessary to reliably identify high-impact contamination events (chemical, microbial, radioactive, pathogens, and biotoxins) in source water and distribution systems in time to allow an effective local response to prevent public exposure to contaminated water resources (ILSI, 1999).

According to the International Life Sciences Institute (ILSI, 1999) many drinking water treatment plant managers perceive pollutants from oil and petrochemical spills, agricultural runoff, and untreated sewage as the top threats to their water supplies. This threat prioritization indicates the treatment needed in an emergency to meet drinking water standards, as well as the parameters that should be considered for incorporation into EWSs (ILSI, 1999).

The sources and impact of adverse water incidences have direct implications for the methods employed in setting up EWS to monitor water resources. Where the focus involves physical water quality variables or contaminants with considerable spatial extent, remote sensing technology as well as measured ground water quality parameters are utilized in the data collection and analysis process. However, if the focus is on chemical and biological water quality variables, the approach is primarily based on real-time continuous monitoring, water sampling, and testing with little or no EO technology.

EWS Trends for Water Quality Assessment and Contaminant Detection

The United Nations Environment Programme (UNEP), through the Global Environmental Monitoring System (GEMS) Water Programme, has been collecting samples and monitoring global water quality from more than 100 countries, with more than two million entries for lakes, reservoirs, rivers, and groundwater systems (GEMS, 2005).In the United States, the Environmental Protection Agency (USEPA), the United States Department of Agriculture (USDA), the United States Geological Survey (USGS), and other research partners and academic institutions are the leading organizations involved in setting up EWSs and contaminant detection platforms for protecting the country's water resources. In Europe, EWSs have been used to monitor water sources and supplies for many years. As characteristic of all EWSs, it could be very costly and labor intensive to set up very reliable and continuous monitoring systems. In situations of high perception of possible risk of contamination, there is always the need for local and regional collaboration to help establish an integrated system with reliable and effective outcomes (Foran and Brosnan, 2000).

USEPA recommends extensive and very sophisticated components for EWSs for WQ assessment, aimed at reliably monitoring surface water systems for traces of chemicals, radioactivity, pathogens, and biotoxins. Such a system is expected to be capable of detecting and measuring:

- Extreme anthropogenic events (e.g., inadvertent discharges/spills), intentional discharges (e.g., bioterrorism, vandalism), as well as cumulative point and nonpoint source pollution
- Extreme natural events that might compromise water quality (e.g., flooding, anoxia, algal blooms)
- Compounds that might pose chronic health risks (e.g., xenoestrogens, biocides, pharmaceuticals, pesticides) (ILSI, 1999)

According to USEPA, a reliable and effective EWS for WQ assessment should be integrated, should be sensitive to detecting a wide range of potential contaminants with minimal false positives/false negatives, exhibit a significant degree of automation, and allow remote operation and adjustment. The system is expected to identify the source of contamination and permit accurate prediction of the location and concentration downstream of the detection point, allowing for rapid response. It should be affordable and exhibit high sampling frequency with multi-parameter and real-time continuous functionality in water environments (ILSI, 1999).

Most EWS field installations have standardized analytical equipment, which requires low-skill training and allows for third-party testing, evaluation, and verification. Required common monitoring methods include colorimetric and membrane electrodes for chlorine, thermistors for temperature, membrane electrodes or optical sensors for dissolved oxygen, potentiometric methods for oxidation-reduction potential, glass bulb electrodes for pH, nephelometric methods or optical sensors for turbidity, conductivity cell methods for specific conductance, and ion-selective electrodes for Cl-, NO3, and NH4+ (USEPA, 2005a).

Basic components of EWSs for WQ assessment follow the same trends as in EWS for environmental degradation; however, the unique characteristics of water pollution contaminants call for specially designed equipment to measure pollutants and allow subsequent processing, analysis, and effective response to possible contaminant threats.

The general components and processes in EWS for WQ contamination assessment are:

- Onsite platforms of contamination monitoring systems—sensor placement and automated samplers (with reliable frequency) for an array of chemicals, radioactivity, pathogens, and biotoxins
- Secure and near-real time data transmission to central data processing centers via direct wire/wireless, phone lines, radio, and satellite
- Data storage, validation, evaluation, processing, and analysis through use of flow and spatial models as well as mathematical/statistical software
- Dissemination of processed data and early warning information to decision-makers and other end-users
- Implementation of an effective and timely response to the early warnings issued (ILSI, 1999)

Setup of EWS for Water Contaminant Monitoring

Sensor Placement and Auto Sampling

While numerous technologies have been deployed for the design of sophisticated sensors capable of detecting a broad range of contaminants, the remaining challenge is the need for strategic placement of such sensors in appropriate land and water bodies to allow for immediate detection of all stream flow contaminants and their dispersion and to allow sufficient time for issuance of appropriate warning and implementation of necessary response (USEPA, 2005a).

In the assessments that have been made within this discussion, it has been argued that since there should be time for action after contamination is detected, sensor platforms should be installed far enough upstream to provide adequate representation of the contamination and enable timely warning (ILSI, 1999). Other factors considered in sensor placement are dispersion (reservoirs, lakes), potential increased risk of undetected contamination that could originate between the monitoring station and the intake, instrument response time, the flow rate, and the nature of the treatment process. To achieve optimum monitoring, a network of interconnected early warning system sensors at selected intake points may be most appropriate (ILSI, 1999).

Ostfeld and Salomons (2004a) have proposed an optimal layout for sensor placement involving the construction of a randomized pollution matrix (RPM) based on the pollution matrix (PM) concept proposed by Kessler et al. (1998), using a genetic algorithm (GA). The randomized pollution matrix and the appropriate number and location of monitoring stations, as well as detection likelihood, arises from the pollution events under consideration, the dilution and self decay/growth of the contaminant during distribution with flow, and the sensor detection capability for various contaminant concentrations (Ostfeld et al., 2004b).

The USEPA proposes the development of a hydraulic model system to assist in sensor placement. According to the USEPA, real-time integrated pressure and flow data can be used to build flow models that have well characterized predictive capabilities (USEPA, 2005a). Other factors considered in determining sensor locations could be location of isolation valves and critical nodes (hospitals, emergency response), as well as physical security or vulnerability of the location. According to the USEPA, even if sensors can be optimally located within a distribution system, there may not be sufficient time to prevent exposure of a portion of the public to the contaminated water source (USEPA, 2005a).

Data Collection, Transmission, and Evaluation

Most sensors typically have some level of communication with a central System Control and Data Acquisition (SCADA) system to automate operations (Roberson and Morley, 2005) and allow for real-time data transfer. Data collection by SCADA is used to handle large data volumes from online sensors in EWSs. Because of the large amount of data generated, automated data validation (Quality Assurance [QA]/Quality Control [QC]) processes are indispensable to ensure accurate results from data analysis (USEPA, 2005a). QA/QC processes can either be manual or automated (Roberson and Morley, 2005). USEPA recommends initial comparison of data received from monitoring sites with data stored at the sensor locations automatically (USEPA, 2005a).

Data Interpretation

A well-defined approach to data interpretation is required to improve the utility of an early warning system (Foran and Brosnan, 2000). EWSs require clearly established contaminant baselines and defined deviations from which risk responses are triggered. Triggers are developed to minimize both false positives and false negatives (ILSI, 1999). Baseline development should be contaminant or event specific and is usually influenced by the toxicity of a compound or pathogen, the nature and extent of the population at risk, and the perceived risks associated with a contaminant's exposure by the public (Foran and Brosnan, 2000). In most cases, such baselines are established by the USEPA in the form of maximum contaminant level (MCL) or established by a research group at the local level.

Arrays of methods are utilized in data analysis and processing. Statistical approaches are used for data analysis and validation. Such approaches include, but are not limited to, single data validation, gap filling, range checking, rate of change checking, and running variance checking (Roberson and Morley, 2005). The process of confirming an incidence of contamination when a baseline trigger is exceeded is an important one. An early warning response could be taken immediately or suspended while re-sampling is conducted to confirm a detected adverse pollution incident. Another key component of EWSs is the ability to predict the fate and flow distribution of contaminates using water quality models (USEPA, 2005a). If properly designed and calibrated, a mathematical model (hydrological) can help estimate longitudinal, horizontal, and vertical dispersion and predict the time of arrival of a given contaminant, and even give an estimate of the concentration to be expected at the downstream locations (Clark et al., 1986).

Monitoring Physical Pollution Variables in Water Bodies

Depending on the nature of water impairment, remote sensing and other EO technologies at appropriate scales and resolutions (spatial, spectral, temporal, and radiometric) have been utilized in data collection and processing for EWS for water quality assessment. Studies on certain physical, chemical, and biological water quality variables such as turbidity/sediments, mud, coastal erosion, fecal or organic and effluent/waste sewage discharges, oil spills, aquatic vegetation / algal blooms, watershed landscape characterization, underground water features, and flood incidence have successfully been conducted in the past utilizing remotely sensed data. Commonly used sensors in water quality EWSs include microwave sensors (Radio Detection and Ranging [RADAR] and Interferometry) and optical sensors (Hyperspectral Sensors, Multispectral Sensors, and Light Detection and Ranging [LIDAR]). Researchers such as Salama and Monbaliu (2004), Sudduth et al. (2005), and others have shown that it is possible to estimate variations in water quality parameters such as sedimentation, turbidity, and chlorophyll and nutrient content from hyperspectral data with promising accuracy.

Salama and Monbaliu (2004) used mapped suspended particulate matter (SPM) from Compact High Resolution Imaging Spectrometer (CHRIS) hyperspectral imagery to show the drastic increase in SPM between 20/09/2003 and 21/09/2003 within the Belgian coastal water. The image analysis shows a drastic increase in SPM between 20/09/2003 and 21/09/2003. SPM serves as an important environmental indicator for water pollution and quality (Salama and Monbaliu, 2004). Sediments can carry absorbed nutrients, pesticides, heavy metals, and other toxins into surface and ground water resources, impairing the water quality and making them a threat to both aquatic and terrestrial organisms, including humans. SPM, as an input layer or final output product from a EWS, provides early warning information on the source, rate, and trend of water pollution and the need for immediate environmental protection measures to reduce an ongoing pollution trend and restore water bodies to a better quality.

Information Dissemination and Response to Early Warning Information

Depending on the nature of a particular threat obtained from the EWS, a chain of communications is triggered to inform major decision-makers, such as local leaders, politicians, law enforcement agencies, first responders, medical personnel, toxicologists, and contaminant experts. Based on their immediate decisions, previously developed emergency response plans are implemented to protect the public and the environment. In cases like common water pollution, plant managers are advised to modify their treatment regimen to neutralize the contaminants and sometimes the general population is advised through all modern communication means on steps to be taken to remain safe, such as boiling tap water before use or a complete ban on water usage. Other responses are strictly dependent on the nature of the pollution level and threat to human and animal health, and such response could be as extreme as evacuations.

Implementing an emergency response plan to an issued early warning before the actual impact is a very difficult task that requires collaborative efforts at all levels of government, including federal, state, county, and local authorities and significant prior planning and practice. U.S. federal agencies , such as the Federal Emergency Management Agency (FEMA), Centers for Disease Control and Prevention (CDC), and the Emergency Management and Emergency Preparedness Office of the U.S. Health and Human Services offer guidelines for emergency response plan development and help coordinate response to major disasters that are overwhelming to local authorities. For continental and global level threats, such as in a tsunami EWS, warning information is communicated by multilateral agencies to decision-makers at national levels via data and information dissemination systems and modern communication techniques, such as phone, fax, email, text messaging, radio and television broadcasting.

HUMANITARIAN EARLY WARNING SERVICE

Under the auspices of the United Nations Inter Agency Standing Committee (IASC), the Humanitarian Early Warning Services (HEWS) web site (HEWSweb) has been set up to provide a common platform and partnership for humanitarian early warnings and forecasts for all natural hazards and socio-political developments worldwide (HEWS, 2007). Globally, IASC through HEWSweb provides to the wider humanitarian community systematic, credible, and real-time early warning on each type of hazard, including those for drought, floods, storms, locusts, volcanoes, earthquakes, El Niño, tsunamis, and other hazards, such as epidemics, epizootics/zoonoses (e.g., avian influenza), as well as socio-political crises. HEWSweb makes accessing such warning information easier and faster. The HEWSweb project, which enhances humanitarian preparedness during hazards, is supported by a variety of partners, including FAO, WFP, UNICEF, UNHCR, UNDP, OCHA, WHO, IFRC, and ICRC, as well as a consortium of international non-governmental organizations (HEWS, 2007).

Based on the recommendations of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), an action team formed by the Committee on the Peaceful Uses of Outer Space (COPUOS) recommended the establishment of an international space coordination body for disaster management, since there are awareness gaps between ongoing or planned space-related initiatives/resources and the disaster management community (Stevens, 2006). The new entity, proposed to be named the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (SPIDER), under the UN Office for Outer Space Affairs, will strive to ensure that all countries have access to and utilize space-based information to support the full disaster management cycle. SPIDER is intended to serve as a gateway to space information for disaster management support, connecting disaster management and space communities while helping in capacity building and institutional strengthening (Stevens, 2006). The SPIDER initiative is expected to work with end-users, particularly in developing countries, through the consolidation of networks of regional support offices, building upon the commitments being provided by many countries to ensure that regional and national centers have a strong role in their respective regions (Stevens, 2006).

Another important humanitarian early warning system is infectious disease informatics. Early detection of infectious diseases is necessary to minimize the number of people infected (Veenema and Tõke, 2006). Advances in information technology have enhanced the possibility for health care organizations and providers to collect, disseminate, and share data. Through surveillance monitoring, integrated data analysis, and visualization techniques, exotic and delayed-presentation diseases can be identified, disease trends tracked, and providers and local authorities alerted to any possible outbreak before further transmission occurs (Veenema and Tõke, 2006). An example of such infectious disease EWS is the avian influenza monitoring system under the HEWSweb project.

There is other detailed research and supporting literature on other EWSs, such as the work of Leach and Dowla (1996) at the Lawrence Livermore National Laboratory on an earthquake early warning system using real-time signal processing and that by Ali and Hui (2006) on the development of a near real-time EWS on erosion hazards.

EVALUATION OF EARLY WARNING SYSTEMS

Great advances in EWSs have been made in the areas of environmental monitoring, reliable impact predictions, and quick and efficient response to possible devastation. These include EWSs on flood predictions, drought and food security, geologic incidents (e.g., earthquakes, landslides, volcanic eruptions, and tsunamis), deforestation, forest fires, desertification, air pollution, and water quality. Critical areas, such as in water pollution and quality studies, have seen increased research globally due to the perceived health risk to human populations.

On regional levels, different regions of the world have had varying degrees of advances in EWS, depending on their most critical environmental and disaster issues. In Africa, there have been advances in food security, climate, and drought early warning systems, together with the establishment of disaster management platforms in several countries (Vordzorgbe, 2003). Asia is making progress at improving forecasting and access to warning information through the development of more comprehensive and user-friendly EWSs, with new interest in hydrometeorological warning systems. In Central America and the Caribbean, advances have been made in the development of EWS for agrometeorological hazards, particularly for windstorms and floods. Less developed EWS in the American hemisphere are EWS for landslides, earthquakes, climate change, and El Niño warning (Vordzorgbe, 2003). Europe has some of the most sophisticated and advanced EWSs with accurate hazard prediction and warnings for floods, climatic change, water quality, and other pollution hazards, integrating the use of internet and satellite technologies for warning information dissemination and well-established response plans (Vordzorgbe, 2003).

Advantages and Strengths of EWS

Successful EWSs have contributed immensely to the protection of life and the environment through the following:

- EWSs serve as a vehicle for environmental protection and sustainability, protecting both terrestrial and aquatic species most vulnerable to environmental degradation.
- EWSs provide warning information that enable policy-makers, first responders, and medical personnel to plan and implement emergency response programs.
- EWSs facilitate decision support systems, providing humanitarian and international organizations important information on poten-

tial human catastrophes from on-going degradation events and enable the formulation of guidelines to resolving such problems.

- Water quality EWSs serve as whistle blowers for the creation and implementation of important environmental protection legislations, such as the USEPA's Interim Re-registration Eligibility Decision and the Clean Water Act (USEPA, 2005b).
- Water quality EWSs also provide water treatment plants with important pollution warning information that is essential for the adjustment of treatment operations to neutralize any contamination and protect human lives.
- EWSs also help identify the source of adverse degradation events, which is important during the restoration of the affected natural resource.
- EWSs encourage general development and the exploration of scientific capabilities, with great technological advances in sensor designs, data analysis, and efficient response plans.
- EWSs promote institutional integration and collaboration.

Disadvantages and Weakness of EWSs

EWSs, while beneficial, do have limitations:

- EWSs can be very expensive, labor intensive, and difficult to establish as automated systems.
- Real-time data collection and transmission is still a challenge in most countries.
- False positive and false negative readings are a source of many unpredicted disasters or misinformation, leading to human fatalities.
- For water quality studies, there is still no best optimal approach to sensor placement that captures potentially all inbound contamination.
- The lack of fully integrated EWSs for important environmental phenomena such as geologic activities, drought, and flooding has resulted in fatalities from incidences such as the 2006 mudslide in the Philippines, 2003, 2005, and 2006 earthquakes in Iran, the 2004 Asian tsunami, and the 2005 U.S. Gulf Coast Hurricane Katrina.
- Where not reliable, EWSs could provide false sense of security and protection.
- The lack of institutional collaboration and partnership from global level to regional, national, and local levels has prevented optimal benefits from EWSs.

DISCUSSION

Over the last decade, there have been dramatic increases in EWSs in almost every area/issue related to human survival. Most existing EWSs have served as important tools in predicting potential catastrophes based upon data from remote and in situ sensors. Such information allowed for some level of preparation that helped in alleviating adverse impacts and human suffering and sometimes prevented the loss of lives and property. The UN has used predictions of drought and food insecurity to plan and organize food aid to most affected regions. Early warning information on possible flooding events and volcanic activities has helped authorities to organize evacuations and assistance programs. A typical demonstration of success in EWSs, according to WMO Secretary-General Obasi, was the death toll of 200 compared to 130,000 from similar cyclones in 1991 and 1994, respectively, in Bangladesh as a result of the advanced warning for the 1994 cyclone.

Despite the great advances in technology and numerous EWSs, most present systems have not completely served their intended purposes. In Africa and elsewhere, EWSs for meteorological events, drought, floods, and food insecurity have not uniformly protected the population from hunger and floods. The 2004 Asian tsunami, the 2005 U.S. Gulf Coast Katrina storm, and the 2006 mudslide in the Philippines are indications that even the most sophisticated EWS may not completely protect all property and life from environmental disasters, as a result of weakness in some parts of the relevant EWSs, especially in areas of public response to official emergency edicts and actions. Despite the worldwide efforts at protecting surface and ground water resources, the world still has too many severely impaired water bodies. Moreover, countries in the Middle East, Asia, and the Americas continue to experience deadly impacts from earthquakes and volcanic eruptions in the absence of good forecasting from reliable EWSs.

CONCLUSIONS

Advancement in technology and communications has given way to very sophisticated early warning systems for environmental monitoring. Most successful EWSs have been for long-term seasonal forecasting, such as for weather, climate, drought, and land degradation trends. Unfortunately, short-term impacts of floods, geologic hazards, and water pollution have generally not been well predicted.

EO technologies have successfully been used in EWSs related to long-term environmental phenomena over large areas such as in most land degradation studies and in investigations related to physical degradation of water bodies and wetlands. There is the need for further research and development in EWSs for water quality assessment related to biological and chemical variables. The use of combined technologies of EO, in situ real-time monitoring of contamination, and the use of versatile hydrological water quality models to predict possible water degradation incidences before they occur would contribute to some of the most reliable and integrated EWSs for water quality.

Many obstacles exist in efforts at establishing EWSs and most need to be addressed to enhance the creation of fully integrated and effectively operational EWSs. Issues related to funding, research, expertise, sound technologies, infrastructure, institutional capacity, collaboration and integration, efficiency in response, improved risk management, as well as communication infrastructure, need be looked at holistically in the process of setting up well-integrated EWSs for all potentially dangerous environmental degradation and pollution sites and vulnerable populations. Equally important components of EWS are emergency preparedness and disaster response plans that are initiated when an adverse impact is predicted and warning information issued. Since this single component determines how lives and property may be saved or lost in case of a devastating incident, it is crucial that such a plan is developed in advance, rehearsed, and ready to be implemented for a wide array of EWSs.

Increasingly, remote sensing has proven to be a good tool for monitoring most environmental and meteorological phenomena, considering its ability to continuously monitor any part of the earth at varied, and possibly very high spectral, temporal and spatial resolutions. The availability of remotely sensed archival data is immensely important in analyzing most environmental degradation trends. The synergy of integrating remote data of varied temporal, spectral, spatial, and polarization scales with appropriate socio-economic data in spatial analysis will highly enhance the setting up of effective early warning systems, especially on global scale phenomena where traditional in situ monitoring may be very difficult, time consuming, and limited in spatial and temporal coverage.

LIST OF ABBREVIATIONS AND ACRONYMS

AU African Union

AVHRR Advanced Very High Resolution Radiometer

CDC Centers for Disease Control

CEDARE Center for Environment and Development for the Arab Region and Europe

CEO Centre for Earth Observation

CHRIS Compact High Resolution Imaging Spectrometer

CNES Centre National d'Etudes Spatiales

COPUOS Committee on the Peaceful Uses of Outer Space

D-DIS Desertification Data and Information System

DDS Data Dissemination Systems

DEWA Division of Early Warning and Assessment

EIS Environment Information Systems

EO Earth Observation

ENVISAT Environmental Satellite

EROS Earth Resources Observation and Science

ESA European Space Agency

ETM+ Enhanced Thematic Mapper Plus

EU European Union

EWS Early Warning System
FAO Food and Agriculture Organization
FEMA Federal Emergency Management Agency
FEWS Famine Early Warning System
fPAR Fraction of PAR
GA Genetic Algorithm
GDP Gross Domestic Product
GEMS Global Environmental Monitoring System
GEO-3 Global Environmental Outlook-3
GIEWS Global Information & Early Warning System
GIS Geographic Information System
GOES Geostationary Earth Observing Satellite
GPP Gross Primary Production
GPS Global Positioning Systems
HEWS Humanitarian Early Warning Service
IASC Inter Agency Standing Committee
IPCC Intergovernmental Panel on Climate Change
ICRC International Committee of the Red Cross
IDS Information Dissemination Systems
IFRC International Federation of Red Cross and Red Crescent Societies
ILSI International Life Sciences Institute
IRS Indian Remote Sensing
ISDR International Strategy for Disaster Reduction
LAI Leaf Area Index
LIDAR Light Detection and Ranging
LNS Local NPP Scaling
LWC Leaf Water Content
MCL Maximum Contaminant Level
METEOSAT Meteorological Satellite
MSI Moisture Stress Index
MSS Multispectral Scanner
MODIS Moderate Resolution Imaging Spectroradiometer
NASA National Aeronautics and Space Administration
NDVI Normalized Difference Vegetation Index
NGO Nongovernmental Organization
NOAA National Oceanic and Atmospheric Administration
NPP Net Primary Production
OCHA Office for the Coordination of Humanitarian Affairs
PAR Photosynthetically Active Radiation
PM Pollution Matrix
RADAR Radio Detection and Ranging
RCMRD Regional Centre for Mapping of Resources for Development
RPM Randomized Pollution Matrix

RUE Rain Use Efficiency
RVI Ratio Vegetation Index
SADC South African Development Cooperation
SAR Synthetic Aperture Radar
SAVI Soil Adjusted Vegetation Index
SCADA System Control and Data Acquisition
SID Society for International Development
SISEI Environmental Information Systems for Sustainable Development in Africa
SPIDER Space-based Information for Disaster Management and Emergency Response
SPM Suspended Particulate Matter
SPOT Système Probatoire pour L'Observation de la Terre
TM Thematic Mapper
UN United Nations
UNCCD United Nations Convection to Combat Desertification
UNDP United Nations Development Programme
UNEP United Nations Environment Programme
UNHCR United Nations Refugee Organization
UNICEF United Nations Children's Fund
USAID United States Agency for International Development
USDA United States Department of Agriculture
USEPA United States Environmental Protection Agency
USGS United States Geological Survey
VAM Vulnerability Analysis and Mapping
WFP World Food Programme
WHO World Health Organization
WMO World Meteorological Organization
QA Quality Assurance
QC Quality Control
WQ Water Quality

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